Working Paper No HDH-13-08e
13th HDH meeting,21/22 March 2013

Issues to be Addressed and Possible Solutions in Introducing HILS into gtr

Report on the Examination of Methods for Matching Integrated power values of WHTC and WHVC by Using HILS

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Background and Objective

Background:

- At the 11th meeting of IG, it was said that the test cycle of the **HILS method will be based on WHVC**.
- At the 7th meeting of IG, it was reported that the power values of WHVC was different from those of the WHTC for conventional motor vehicles.
- To match the duty cycles of conventional vehicles and HEVs, it is **necessary to match the cycle work on the positive side between WHTC and WHVC** at least.
- The power patterns on the negative side are only for engine friction if WHTC is as it is, so it is desirable to determine on a vehicle-by-vehicle basis.

Objective: Examine the Methods for matching integrated power values on the positive side between WHTC and WHVC by using HILS.

Parameters that can be changed to match integrated power values

The preTM power while running in WHVC may be obtained from the formula (1):

$$P_{WHVC} = \left(mg \sin\theta + \mu_r mg + \mu_a A V^2 + (m + \Delta m)\alpha \right) \omega_T / \eta_d \eta_{TM} \quad (1)$$

Here, P_{WHVC} = preTM power, m = vehicle mass, g = gravity acceleration, θ = slope, μ_r = rolling resistance coefficient, μ_a = air resistance coefficient, A = total projected area, V = vehicle speed, Dm = rolling inertia mass, a = acceleration, ω_T = tyre rotating speed, η_d = differential transmission efficiency, and η_{TM} = TM transmission efficiency.

In the formula (1), the rolling resistance coefficient, air resistance coefficient, and transmission efficiency are prescribed in Japanese regulations on testing methods, so we see that parameters that can be changed are the slope and vehicle mass. Based on the specifications of actual vehicles indicated in Table 1 and using HILS, we examined how we could match the power of WHTC and WHVC by changing slope.

Note: As WHTC, we used the file: WHDC_FE04 (WHTC (Ver.2_n_pref_4) & WHSC_final)

Table 1 Vehicle specifications used in the examination

Vehicle specifications	
Equivalent mass (engine)	0.03
Equivalent mass (tyres)	0.07
Curb vehicle mass [kg]	4,730
Maximum laden mass [kg]	3,150
Capacity	2
Overall height [m]	3.320
Overall width [m]	2.310
Tyre radius [m]	0.389
Number of gears in the main transmission	6
1st gear ratio	6.718
2nd gear ratio	4.031
3rd gear ratio	2.303
4th gear ratio	1.443
5th gear ratio	1.000
6th gear ratio	0.740
Final gear ratio	4.875
Idling revolution speed [rpm]	570
Rated revolution speed [rpm]	3,000
Revolution speed limit with load [rpm]	3,400
Maximum engine power [kW]	152
Motor power [kW]	55

Matching integrated power values by giving slopes

Torque patterns are calculated by dividing each of the power patterns of WHTC and WHVC by the tyre rotating speed obtained from the vehicle speed of WHVC. Using the torque difference between WHTC and WHVC, a slope necessary for matching power in time history ("instantaneous slope") is calculated from the formula (2):

$$\theta = \tan\left(\mathrm{asin}\left(\left(\tau_{WHTC} - \tau_{WHVC}\right)/\left(rd \times g \times m\right)\right)\right) \times 100 \qquad (2)$$

Figure 1 shows the instantaneous slope thus calculated. With the maximum slope of about 37°, the value obtained seems unrealistic (the maximum slope in Japan being 12%). So, we checked in HILS the rate at which integrated power values match between WHTC and WHVC giving three types of slopes: (1) instantaneous slope, (2) smoothed slope, and (3) constant slope.

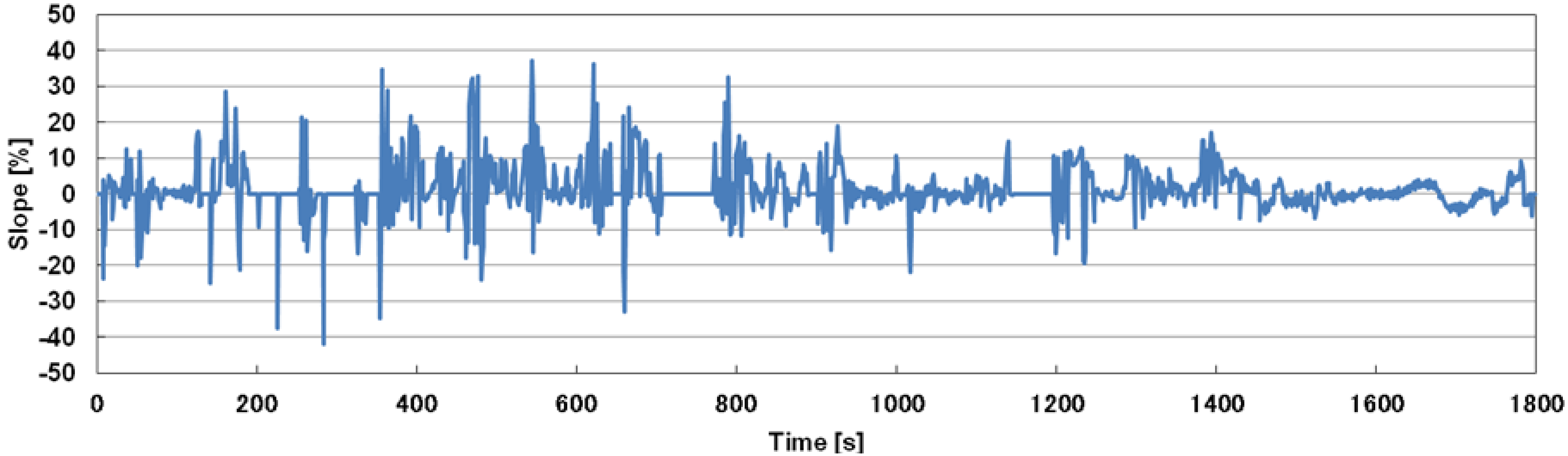

Fig. 1 Instantaneous slope

Results of HILS with instantaneous slopes

Figure 2 shows the results of running in WHVC with the instantaneous slopes calculated above. From Figure 2, we see that the vehicle became unable to track the reference vehicle speed from the sixth peak, where the slope value and change started to increase, and that, around 500 sec., the vehicle speed dropped almost to 0 km/h.

This was because there occurred a crutch-related error in Hybrid ECU. This means that, the method for matching integrated power values by giving instantaneous slopes is not applicable to some vehicles for simulation purpose.

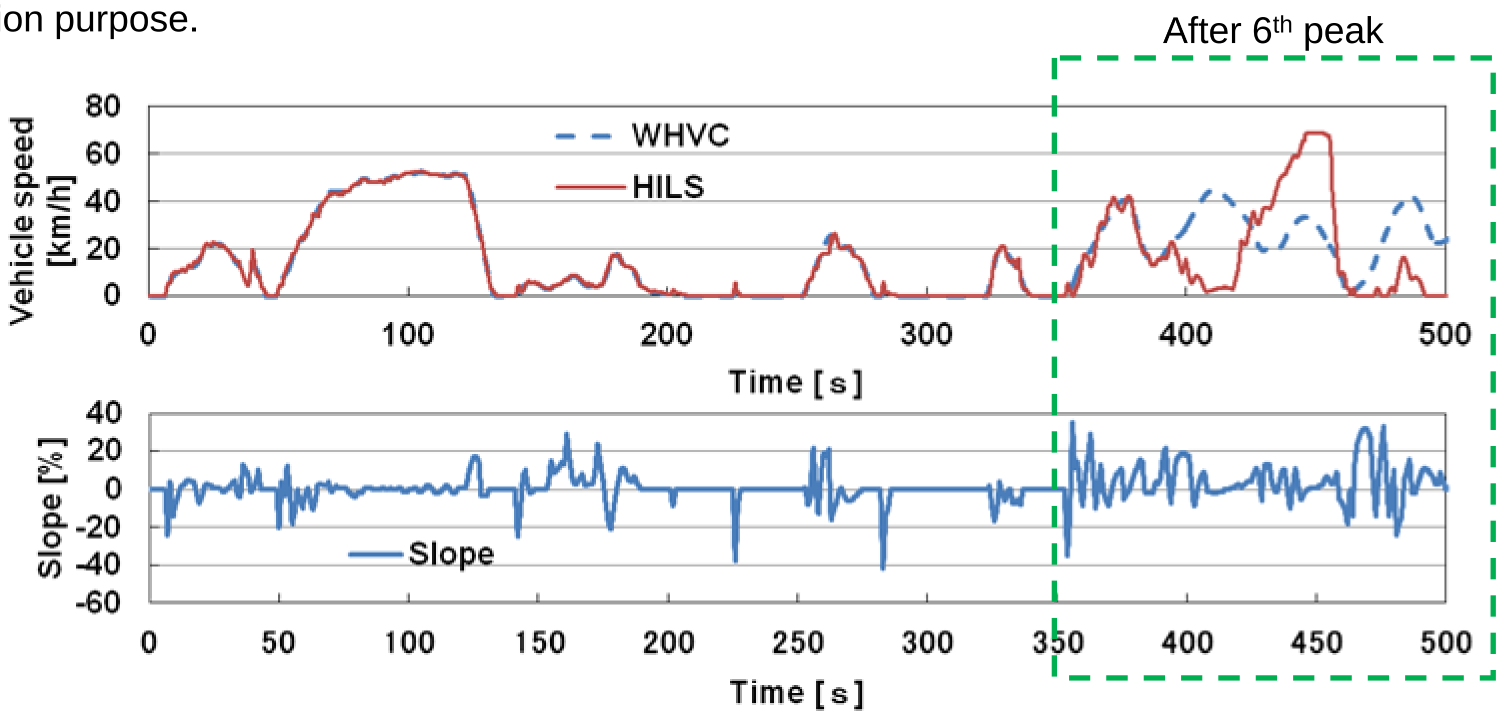

Fig. 2 Results of running in WHVC with instantaneous slopes

*** Without any refined driver model, etc.**

Why do the instantaneous slopes increase?

A possible reason why instantaneous slopes increase is the transmission shift changing behaviors assumed in WHTC. In WHTC, changes in revolution speed and torque presumably caused by shift change shown in Fig. 3, in other words, power changes (gear shifting gap) shown in Fig. 4 occur.

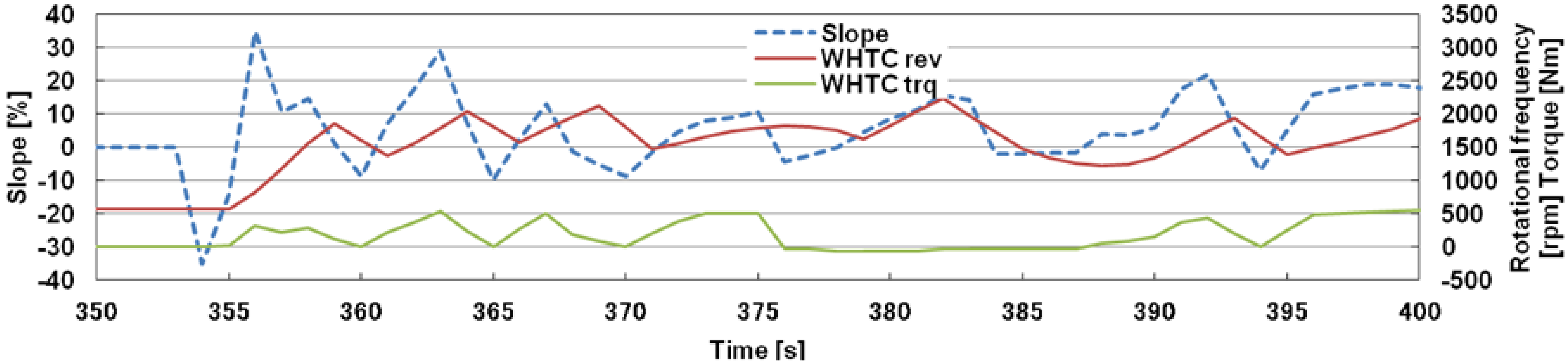

Fig. 3 Instantaneous slopes vs WHTC revolution speeds and torques

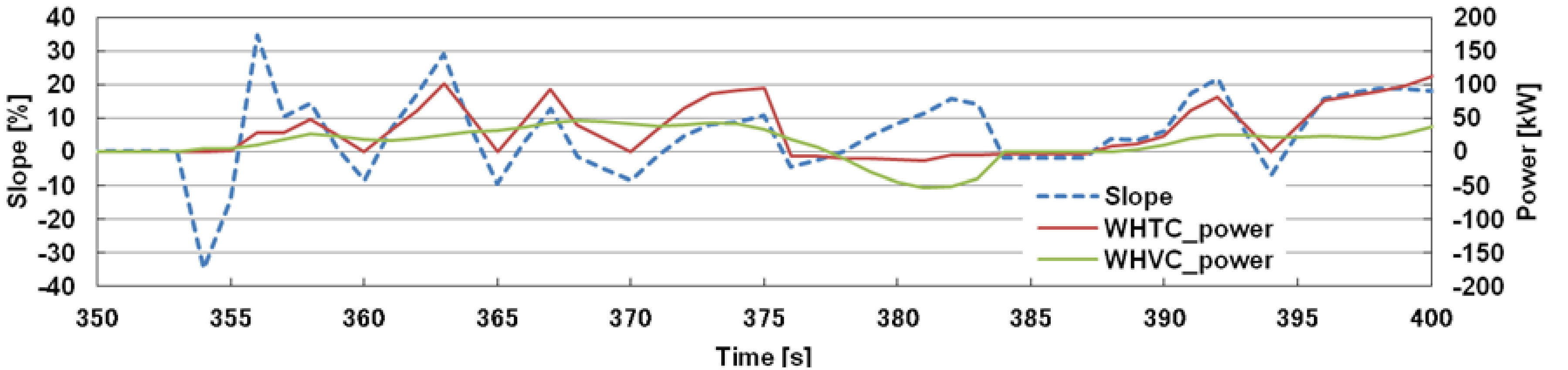

Fig. 4 Instantaneous slopes vs WHTC and WHVC power

Influence of transmission shift changing gaps

Figure 5 shows the slopes calculated based on the power patterns of WHTC to fill the transmission shift changing gaps defined in WHTC, by using a 3-second moving average for slopes while shifting and one second before and after shifting. The maximum slope decreased slightly, but is still over 30%. This may be because a 3-second moving average was not sufficient to significantly change power peaks. To fill the transmission shift changing gaps, we need to find another way.

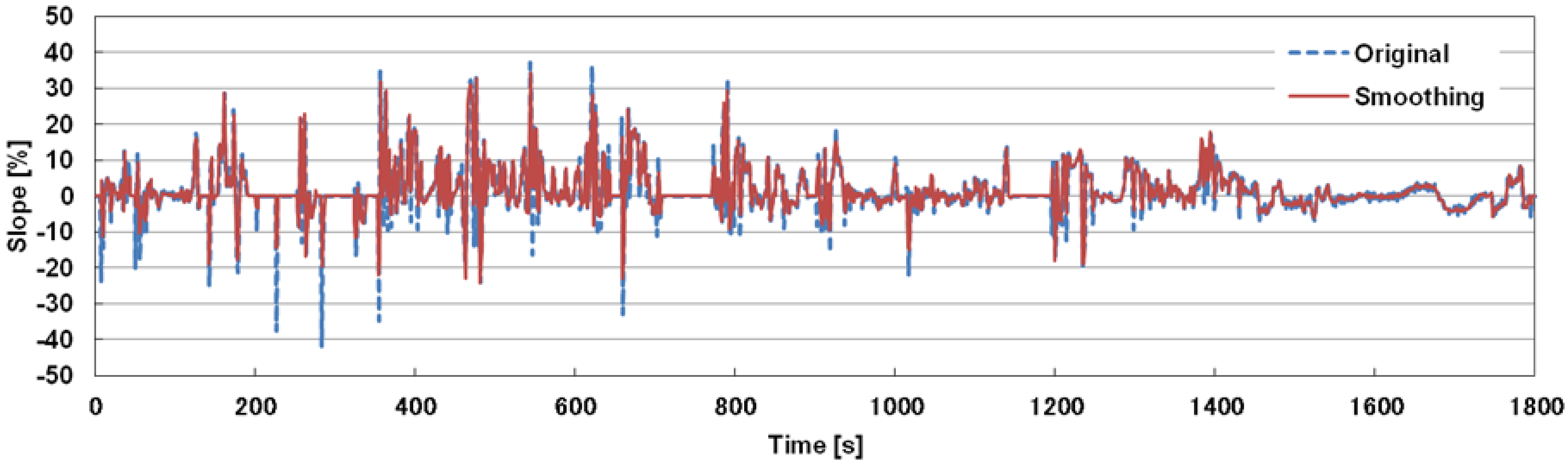

Fig. 5 slopes calculated after filling the transmission shift changing gaps in WHTC power

Matching integrated power values by giving smoothed slopes

When giving instantaneous slopes to match integrated power values, some vehicles may cause ECU errors. So we need to change the maximum slopes and slope changing rates to values acceptable for all test vehicles.

To change these values, three methods may be envisaged.

(1) Limit the maximum slopes.

(2) Set out the limitation on the slope changing rate.

(3) Use an x-second average of instantaneous slopes so that they satisfy the (1) and (2) above.

=> Using the method (3) above, the instantaneous slopes were smoothed using a 30-second moving average so that they don't exceed the maximum slopes for prescribed designed speeds for Japanese roads. Figure 6 shows the slopes smoothed using the moving-average ("moving average-filtered slopes").

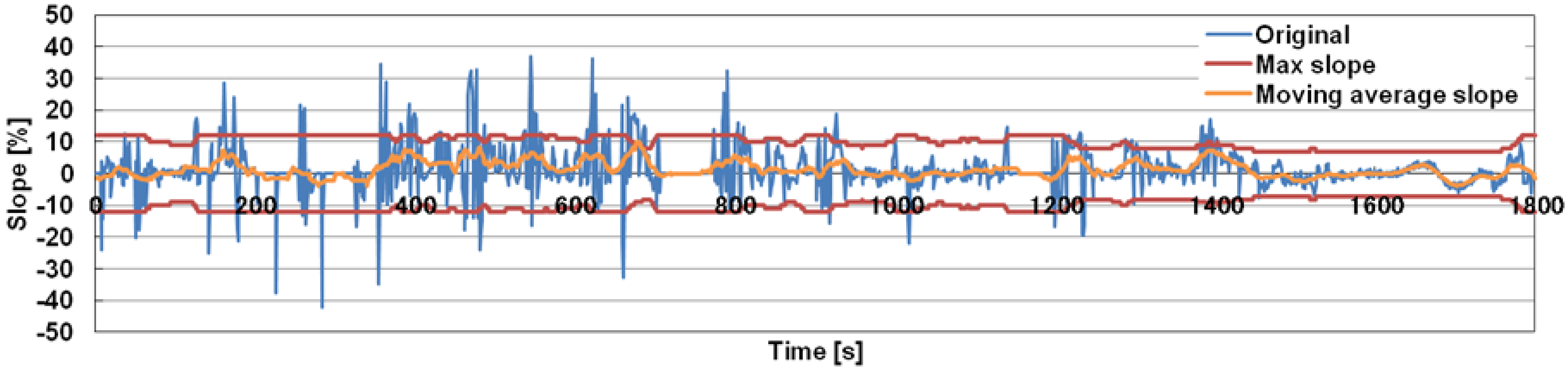

Fig. 6 Moving average-filtered slope

Results of HILS with moving average-filtered slopes

Figure 7 shows the results of simulation of running in WHVC with moving average-filtered slopes. By limiting the maximum slopes and making slope changes smoother than instantaneous slopes, running in WHVC is now made possible. The integrated power values on the positive side was 14.26 kWh (102.9% of WHTC) and the amount of regeneration was 2.67 kWh.

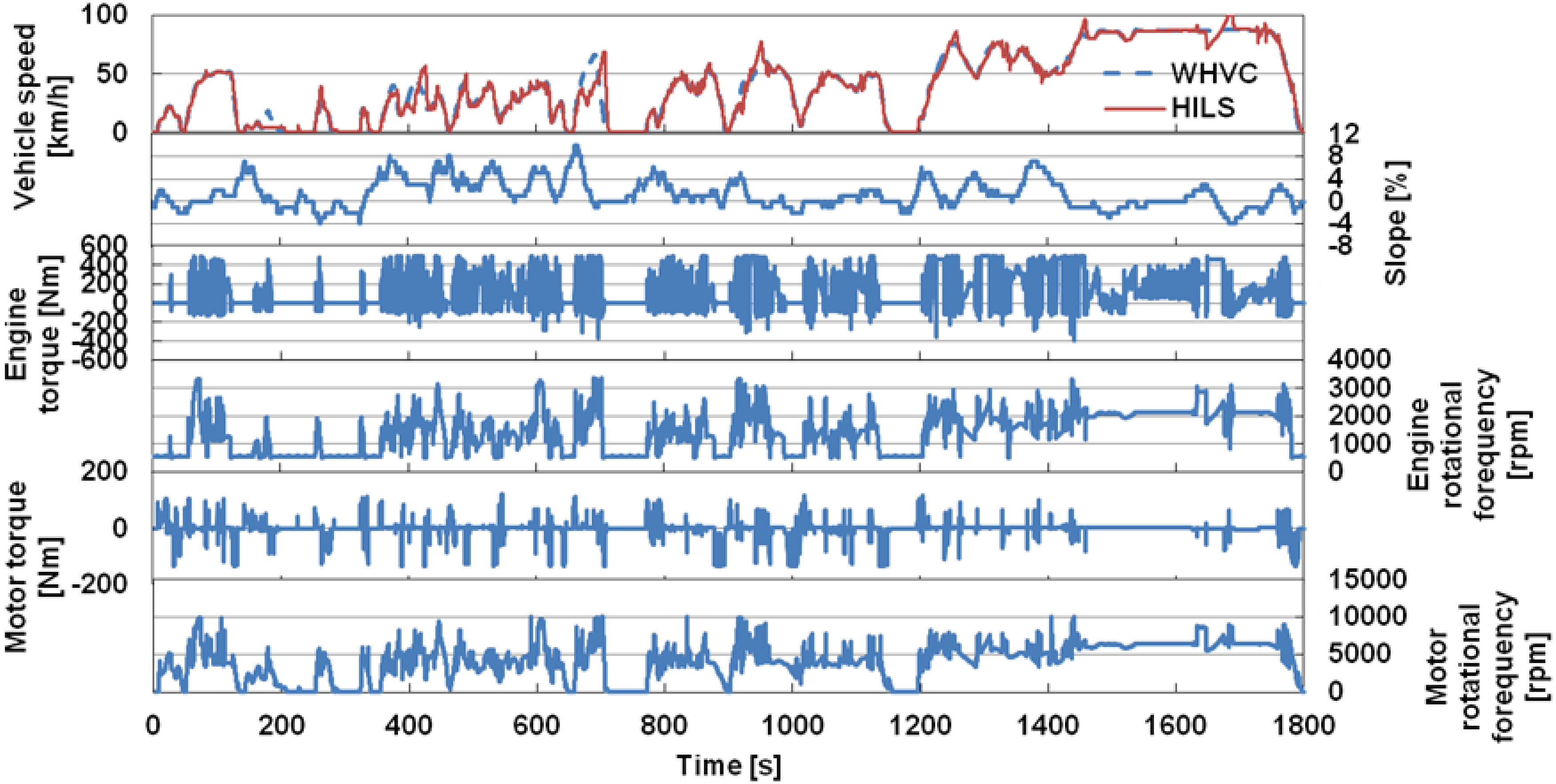

Fig. 7 Results of running simulation in WHVC, with moving average-filtered slopes

***Without any refined driver model, etc.**

Matching integrated power values by giving a constant slope

A possible way to calculate a constant slope is as follows: Since the integrated power values on the wheel hub may be obtained from the formula (3), the differences between the integrated power values in WHTC and WHVC may be obtained from the formula (4).

$$\int Pdt = \int \omega_T \tau dt \tag{3}$$

$$\int (P_{WHTC} - P_{WHVC})dt = \int \omega_T (\tau_{WHTC} - \tau_{WHVC})dt \tag{4}$$

Further, replacing the torque differences in the formula (4) with the slopes from the formula (2) gives the formula (5). Supposing that the slope is constant, θ becomes a coefficient, and may be transformed as in the formula (6), and necessary slope may be calculated.

$$\int (P_{WHTC} - P_{WHVC})dt = \int \omega_T \times rd \times g \times m \times \sin\left(\mathrm{atan}\left(\theta/100\right)\right)dt \tag{5}$$

$$\theta = \tan\left(\mathrm{asin}\left(\int (P_{WHTC} - P_{WHVC})dt \Big/ \left(rd \times g \times m \times \int \omega_T dt\right)\right)\right) \times 100 \tag{6}$$

The constant slope calculated from the formula (6) is 1.13%. This method has a disadvantage of not correctly reflecting the characteristics of hybrid vehicles to the test results, because it gives a constantly uphill slope and reduces the amount of regeneration of braking energy. Further, supposing a slope constantly uphill from the starting point to the parking point gives a road configuration that is actually inexistent.

Results of HILS with a constant slope

Figure 8 shows the results of running in WHVC with a constant slope of 1.13% thus calculated. In some parts, the vehicle couldn't keep the target vehicle speed because the driver model, etc. wasn't adjusted, but managed to run in WHVC. The integrated value on the positive side was 14.30 kWh (103.2% of WHTC) and the amount of regeneration was 2.23 kWh.

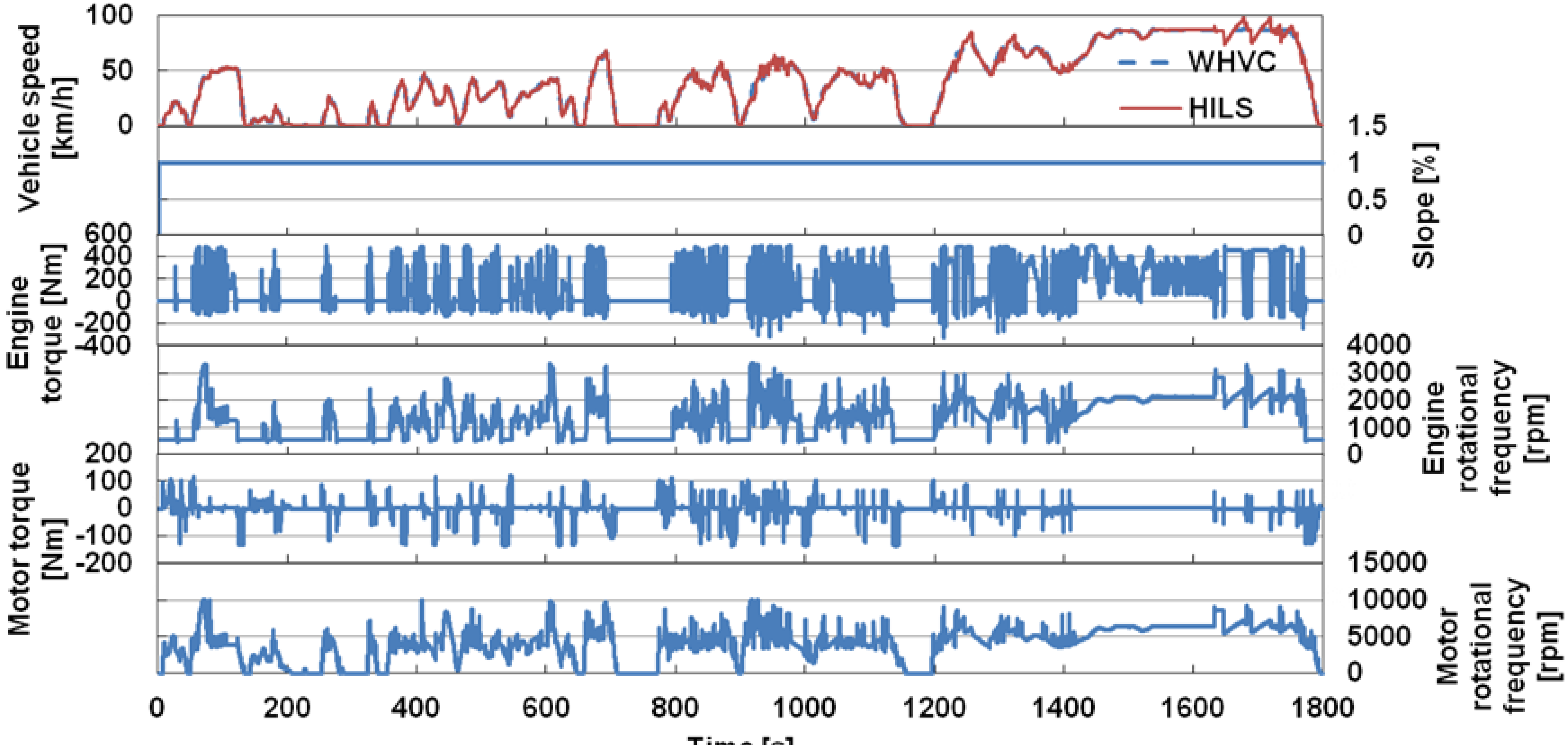

Fig. 8 The results of running in WHVC with a constant slope

*** Without any refined driver model, etc.**

Summary

Figure 9 shows the integrated power values in time history on the positive side with a moving-average-filtered slope and a constant slope compared with no slope. It shows that, compared to when no slope is given, the integrated power value is close to WHTC.

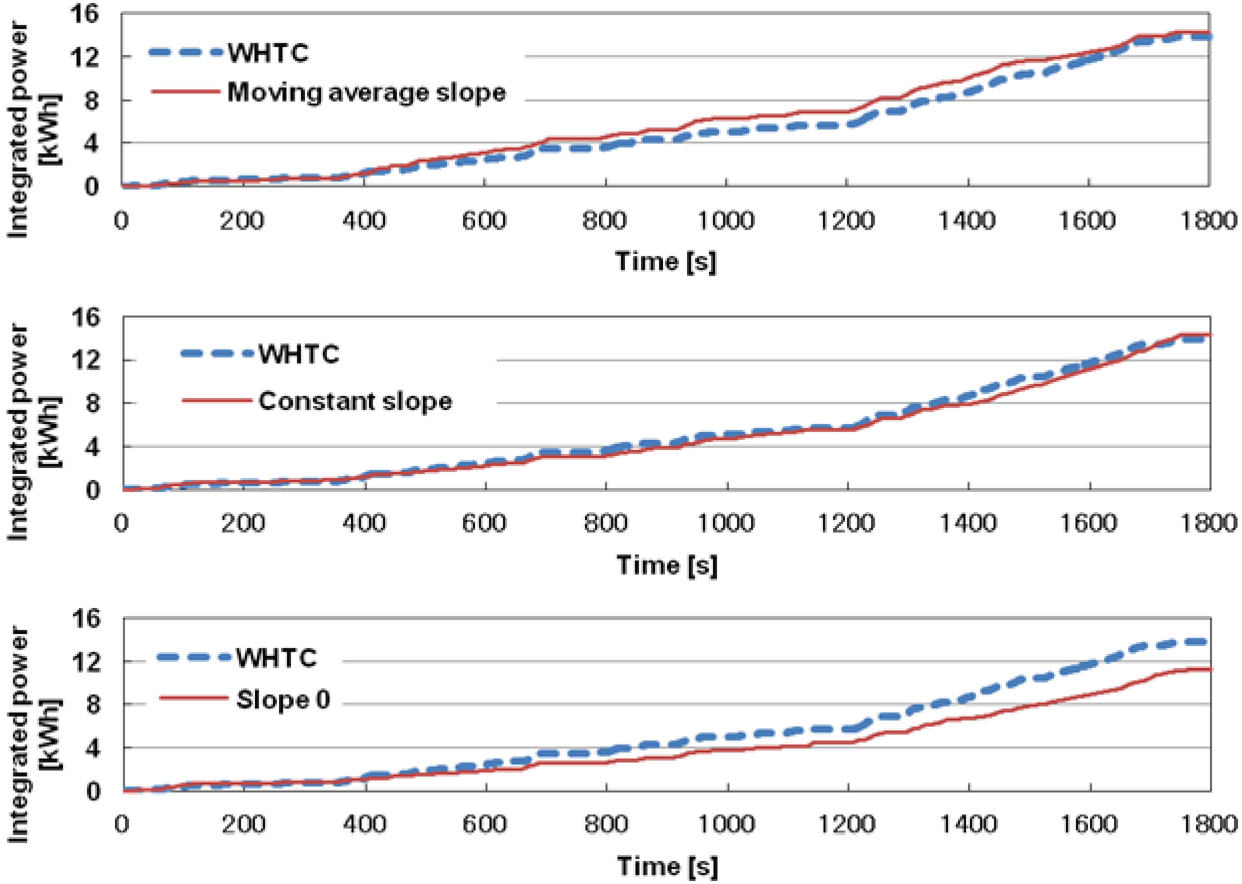

Fig 9. Integrated power values in time history on the positive side with different parameters

Summary (continued)

Table 2 shows integrated power values on the positive side by each of the proposed methods.

Table 3 shows the advantages and disadvantages of each method.

- Instantaneous slopes: Can't run.
- Moving average-filtered slopes: Can match integrated power values. Can approximate power to a certain extent in time history.
- Constant slope: Can match integrated power values. Simple calculation.

The results of examination show that by giving slopes other than instantaneous slopes, we can approximate the integrated power values of WHTC and WHVC on the positive side. However, as to the method for calculating moving average-filtered slopes, further study is necessary.

Table 2 Integrated power values on the positive side by each of the proposed methods

	Integrated power value on the positive side [kWh]	Integrated amount of regeneration [kWh]	Matching rate [%]
WHTC	13.85	1.09	-
Instantaneous gradient	-	-	-
Moving average-filtered gradient	14.26	2.67	102.95
Constant gradient	14.30	2.23	103.21
Zero gradient	11.29	2.51	81.49

Table 3 Comparison of proposed methods for matching integrated power values on the positive side

Change coefficient	Advantages	Disadvantages
Instantaneous gradient	Can match power in WHVC and WHTC instantaneously	May cause ECU errors because of unrealistic gradients and changes
Moving average-filtered gradient	Can match integrated power values in WHVC and WHTC	Method of calculating gradient is complicated and varies with test vehicle. May reduce regenerated energy.
Constant gradient	Can match integrated power values in WHVC and WHTC	Regenerated energy reduces when a constantly uphill gradient is given. Gives a road configuration actually inexistent.